HORIZONTAL BIAS COMBUSTION BURNERS FOR LOW RANK COAL OF CHINA

Sun Shaozeng, Li Zhengqi, Wang Zhijing, Sun Rui, Wu Shaohua, Qin Yukun & Zhang Yong

ABSTRACT

This paper analyses feature of coal for electric power generation in China, clarifies the concept of Horizontal Bias Combustion (HBC) burners, and demonstrates some of the applications of HBC burners in boilers of different capacities and with various types of coal, with emphasis being laid on a 200MW boiler fired with anthracite. Technical measures taken in the burners as well as the firing systems are described and results are compared with those obtained in bituminous coal and lean coal. The HBC burner was capable of abating NOx emission by up to 54% and ensuring the boiler to operate at a rate as low as 45% of MCR without resorting to supporting fuel oil, with an improvement in shut-down ratio by 20 ~ 35%. Other merits of HBC burners like avoiding slagging and increasing combustion efficiency are also shown. It is a technology of multifunction and of great promise.

Key Words: burners, low rank coal, bias combustion, flame stabilisation, NOx reduction

1 INTRODUCTION

Features of Coal for Power Generation in China

Coal is the most important energy source in China. For instance, about 82% of electricity was generated by thermal power station, in which coal accounted for about 80%. Four hundred million tons of coal, i.e. 35.4% of coal produced by China was fired for power generation and for regional heating. The percentage will reach 40% by 2000 and it will be even higher in the next century.

The energy policy of China -- among the power fuels, the low rank coal is for electric power generation -- is a realistic long-term policy. Statistics showed that the low rank coal accounted for 10 ~ 17% of total coal for power generation from 1977 to 1980. Besides, the anthracite which took 3 ~ 4% of total coal for power generation could only be fired in electric power plants. During the period power plants fired with low rank bituminous coal and anthracite amounted to 40 in number with a total capacity of 8500 MW, which took one fifth of the total capacity of electric generating units (Yuan Ying and Zhao Zhonghu (1989)). Moreover, a portion of difficult lean coal, which amounted to 5 ~ 10% of total coal for electric power generation, also brought about many difficulties to power plants (Zhang Mingchuang (1990)).

In last few years, coal supply for power plants was short in China, which caused the quality of coal for power generation to lower considerably. For instance, the heating value of coal decreased by 20% and the ash content increased by 10% (Gu Pan (1992)). A new statistics made on 50 power plants and 91 types of coal showed that anthracite took 24.2%, and lean coal 15.4%. The two categories of coal amounted to 39.6%. On the other hand, high ash coal accounted for 16.7% (Feng Junkai (1995)). The low quality of coal resulted in a series of problems in the operation of the boiler: lack of flame stability and boiler safety, low combustion efficiency, slagging, and fire side high temperature corrosion of furnace tube metal.

Anthracite, lean coal and low rank bituminous coal are all low in reactivity and often high in ash. Therefore they are difficult to ignite and burn stably, which brought about troubles in boiler operation. Furthermore, it was difficult to supply coal stably with reference to coal type and coal quality in China. The frequent fluctuation of coal made the flame stability problem even more baffling. To avoid puff and explosion, supporting fuel oil (10 ~ 15% of total thermal output) was often needed at low load or even at full load in some power plants. The supporting fuel consumed by power generation in China was 15 ~ 20 million tons per year, which raised the cost for electric power generation by 15 ~ 20 billion Yuan RMB.

On the other hand, because of the difficulty in ignition, the ignition was usually delayed and the time left for burning was shortened. Furthermore, the stability of the flame was poor, which resulted in lower temperature of flame. These two factors, combining together, lowered the combustion efficiency considerably, raised the coal consumption for power generation and accordingly decreased the economy of the power plant.

Poor flame stability also hampered the safety of the power plant because it might cause extinction and explosion accident. The extinction accident was the second most frequent one only to the 'four tube' failure accidents and amounted to hundreds each year, which was an important cause for accidental shutdown of 200 ~ 300 MW units (Zhang Mingchuan (1990)). Besides jeopardising the safety and dependability of the boiler, it also hampered the civility of power generation.

Slagging was another problem that endanger the safety and dependability of the boiler operation. In China, coal that had slagging tendency account for 45%, and it is clear that all types of coal with low ash fusion temperature (ST < 1350 °C) would surely lead to severe slagging (Feng Junkai (1995)). Slag accumulated in the furnace disturbed the aerodynamic field and worsened the combustion condition. It might lead to the burnout of the burner nozzles and the failure of superheater tubes because of the excessive high gas temperature. The very big lumps of slag fallen from the top might damage the waterwall tube in the hopper part or even cut off the furnace. The fallen big lumps of slag might vaporise the quenching water and the ash disposal water in such a high speed that the pressure of the furnace might fluctuate violently and might bring about extinction. The big lump of slag might also choke the slag disposal facilities, lead to slag accumulation up from the hopper of the furnace and force the boiler to shutdown.

If the sulphur content of the coal was high and the coal-and-air stream deflects excessively, fireside high temperature corrosion of furnace waterwall tubes might occur. If the primary-air-and-coal nozzles were concentrated, or vertical bias combustion burners are adopted, the high temperature corrosion might be more serious. Not only did it result in the increase in waterwall tube maintenance cost, but it also jeopardised the economy and dependability of the boiler operation.

The development of power industry not only brought about the expansion of the electrically network, but also lead to the increase in the difference between the peak and the valley load of the electrically network. For example, the maximum difference of the peak and the valley load of The Northeast Electrically Network was 37% of its maximum load, and that of The North China Electrically Network was 40% of its maximum load. This demanded that the electric generating units operated at lower load during the valley load period of the network. For instance, in The Northeast Electrically Network, the unit of 200 MW must be capable of operating stably at 50% of its MCR without resorting to supporting fuel oil. This new requirement of flame stabilisation at low load was difficult to meet by the conventional combustion technologies. Consequently, combustion technologies of good flame stabilisation are urgently needed.

Another problem was the combustion induced environmental pollution. In China dominant parts of pollutant emissions came from coal combustion. Among the total pollutant emission, 90% of SO_2, 70% of dust, 67% of NOx and 71 of CO (Xu X. C. and Zhang X.Y. (1991)) were produced by burning coal. In the South-west of China and Hunan province, there occurred large area of acid rain, with trend of further spreading.

It is impossible to reduce coal consumption in China. The only possible alternative is to develop clean coal technologies in order to decrease the pollutant emission and improve the efficiency of coal utilisation.

China has enacted legislation to control SO_2 emission in 1992 and NOx in 1997. However, research and development of gaseous pollutant control technologies were still under development. For instance, the major technology applied by boiler manufacturers has been the NOx control technology -- LNCFS -- which was adopted from the Combustion Engineering Inc (C-E). The technology can reduce the NOx emission of bituminous coal fired boiler to a satisfactory level. However, for difficult coals, the emissions exceeded the standard set by the legislation, Table I. Therefore, low NOx combustion technologies suitable for low rank coal of China are urgently needed.

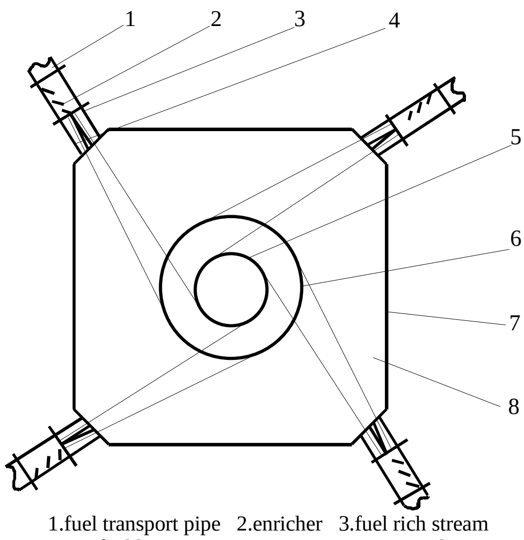
Table I NOx and SO_2 emissions from 300 and 600 MW boiler made by HBW (Sun Shaozeng (1995))

Item	Unit	Pingwei Power Plant		Hnangtai Power Plant		Hualu Power Plant		Mawan Power Plant
		Boiler #1	Boiler #2	Boiler #7	Boiler #8	Boiler #1	Boiler #2	
Load	MW	571~591	560	280	278	285	297	292
O_2	%	2.9~3.97	7.37	5.36	5.3	7.89	7.92	5.37
NO (O_2=6%)	ppm (lb/MBtu)	227~321 (0.25~0.35)	240 (0.26)	449	362	384	448	443
SO_2	ppm	0	0	616	823	480	690	

As discussed above, major problems existing in the coal combustion in China were: deficiency in flame stabilisation (including for low rank coal and at low load), low combustion efficiency, slagging, fire side high temperature corrosion of furnace waterwall tubes and pollutant emission. In order to make boiler units operate economically, safely and dependably, five problems aforementioned have to be solved simultaneously

Concept of Horizontal Bias Combustion Burners

In 1987 we proposed first idea of horizontal off-stoichiometric combustion, which has been developed, eventually to the concept of Horizontal Bias Combustion technology (HBC). The HBC Burner was developed aiming at simultaneously solving five problems, i.e. combustion efficiency, flame stabilisation, slagging, high temperature corrosion of furnace wall tube metal and NOx emission, that existed in burning low rank Chinese coal. It was developed for tangential fired system. The HBC burners are usually facilitated in the following way (Figure 1).



1.fuel transport pipe 2.enricher 3.fuel rich stream
4.fuel lean stream 5.inner imaginary circle
6.outer imaginary circle
7.water-cooled wall 8.oxidizing zone

Figure 1 Diagram of HBC system

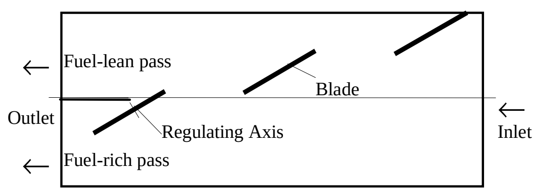


Figure 2 Diagram of Louver Enricher

A Fuel enricher of high enriching ratio is installed in each of the fuel transport lines, which separates horizontally each fuel/air stream into two streams of a big fuel concentration difference. Each of two streams is directed into the furnace at the same elevation, with an angle $\alpha(0<\alpha<15°)$ between their axes. The enriching ratios are so large that the fuel concentration in the fuel rich streams are several times higher than that in the fuel lean streams. Facing high temperature gas, the fuel rich streams inject through the fuel rich nozzles, forming high temperature flame core in the central zone of the furnace, while the fuel lean streams inject through the fuel lean nozzles which locate between fuel rich nozzles and furnace walls upstream them with regard to the whole gas rotational direction, blanketing high temperature flame core with an out layer of more oxidising atmosphere.

In the HBC burners, the louver enricher is adopted, as shown in Figure 2. The blades separate the particles and air partially, forcing most particles to flow through the fuel-rich pass while maintaining certain air flowrate partition.

Main parameters of the HBC system are:

The enriching ratio R_C: The ratio of pulverised coal concentration of the fuel-rich stream to that of the fuel-lean stream.

The air splitting ratio R_Q: The ratio of the air flowrate of fuel-rich stream to that of the fuel-lean stream.

The area ratio R_A: The ratio of exit crosses section of fuel-rich nozzle to that of the fuel-lean nozzle.

That is:

$$R_C = C_{fr}/C_{fl}; R_Q = Q_{fr}/Q_{fl} \tag{1}$$

2 APPLICATIONS OF HBC BURNERS IN POWER PLANTS

HBC burners were used in the retrofits of 16 pulverised coal fired boilers from 1993 to 1999. This technology is now widely accepted in the power industry and boiler manufacture industry in China. Most of the major boiler manufactures, such as Harbin Boiler Work, Dongfang Boiler Work, and Beijing Babcock & Wilcox Co. Ltd, has accepted the technology. As a result, more than ten new boiler units, from 50MW to 350MW, which adopt HBC system, are scheduled to put into operation in one or two years. Moreover the State Power Company of China is planning to spread the technology all over China.

This paper introduces the operation results in boilers firing different kinds of coal, especially low rank coal. The boiler capacities, types and analyses of coal fired, main problems existing in boilers before they adopted HBC burners, main technological measures taken in HBC burners and other part of the firing system, and the parameters of HBC burners are listed in Table II. Arrangements of HBC burners' nozzles are shown in Figure 3.

3 RESULTS AND DISCUSSION

NOx Emission

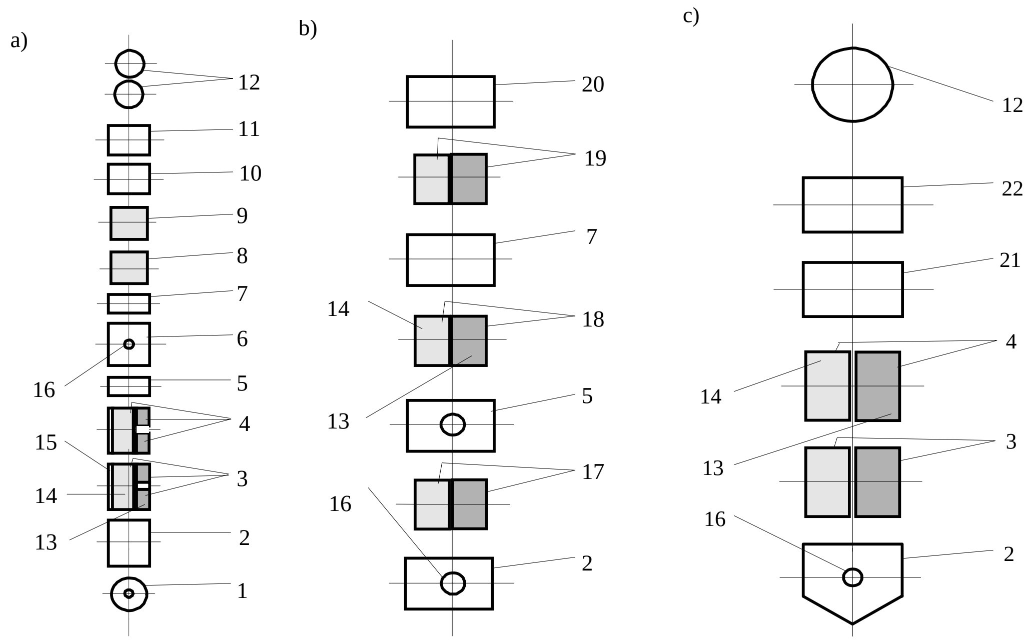
The HBC burners apply the off-stoichiometric principle. Therefore they can reduce NOx emission of the boiler. NO emissions from boilers of different coal are shown in Figure 4.

Boiler rated capacity (t/h)		410	40	670 (200MW)
Type of coal		Bituminous coal	Lean coal	Anthracite
Coal Analysis	V_{daf} (%)	39.94	15.72	10.07
	A_{ar} (%)	20.88	24.45	15
	M_{ar} (%)	11.13	7.42	11.6
	$Q_{net,ar}$ (kJ/kg)	19732	23070	24880
Problems before adopting HBC burners	Flame stability and boiler shutdown ratio	Not good, 70%	Very poor, supporting fuel oil was needed all the time.	Not good, 75%
	Combustion efficiency	good	Terribly low.	Reasonable
	Slagging	Serious. The boiler could not operate at high load (90 ~ 100 % MCR) continuously due to slag accumulation	Generally serious with refractory belt.	Serious. Slag lumps' dropping-down often caused extinction
	NOx emission (ppm, 6 % O_2)	451	322	-

Degree of HBC burners adoption		All burners adopted HBC burners	All burners adopted HBC burners	Only the lower two rows of burners, i.e. half of burners adopted HBC burners
Technical measures taken	R_A	1	2/3	~2/3
	R_Q	1.4	2/3	~2/3
	PA direction	Oppositely directed	Fuel-rich PA oppositely directed	Fuel-rich PA oppositely directed
	Type of divisions between fuel-rich and fuel-lean PA	Plane plate divisions	V-shaped divisions	V-shaped divisions with disturbers
	Enricher's adjustability	Not adjustable	Last blade adjustable	Last blade adjustable
	Refractory belt improvement	No refractory belt	Improved	Improved
	Other measures to enhance flame stability	No	No	Disturbers at the fire facing side of fuel-rich nozzles of the burner; Bluff bodies with disturbers in fuel-rich nozzles.
Parameters of HBC burners	PA ratio (%)	29	20	20
	PA velocity (m/s)	26	21	20.8
	PA temperature (°C)	57	244	277
	SA ratio (%)	67	52	61.4
	SA velocity (m/s)	48	45 (Bottom SA 40)	43.4
	SA temperature (°C)	320	355	374
	TA ratio (%)	20	-	14.6
	TA velocity (m/s)	53	-	53.5
	TA temperature (°C)	90	-	120
Figure of HBC burner nozzles		Figure 3b	Figure 3c	Figure 3a

Table 2 Summary of typical HBC burners' application

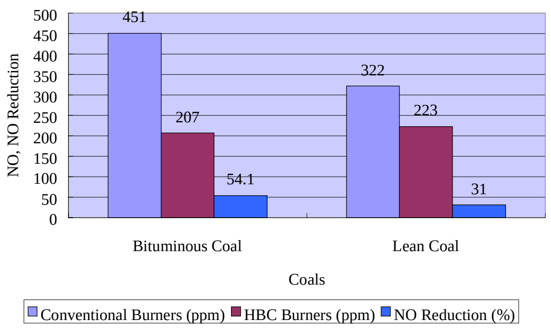
With lean coal, NOx was reduced by 31% by adoption of HBC burners, while with bituminous coal it was abated by 54%. It is a pity that no data were available in the case of anthracite, as only half of the conventional burners were replaced by HBC burners, and the amount of NO emission of the boiler represent neither that of HBC burners, nor that of the conventional burners.



1 start-up oil gun register 2 bottom secondary air (SA) nozzle
3 lower-bottom coal-and-primary-air (PA) nozzle 4 upper-bottom PA nozzle 5 lower-middle SA
ozzle 6 low-load oil gun register 7 upper-middle SA nozzle 8 lower-top PA nozzle 9 upper-top PA
nozzle 10 lower-top SA nozzle 11 upper-top SA nozzle 12 tertiary air (TA) nozzle(s)
13 fuel-rich stream nozzle 14 fuel-lean stream nozzle 15-side SA nozzle 16 oil gun
17 bottom PA nozzle 18 middle PA nozzle 19 top PA nozzle 20 top SA nozzles
21 lower-top SA nozzle 22 upper-top SA nozzle

a. anthracite fired b. bituminous coal filed c. lean coal fired

Figure 3 HBC burners' arrangement



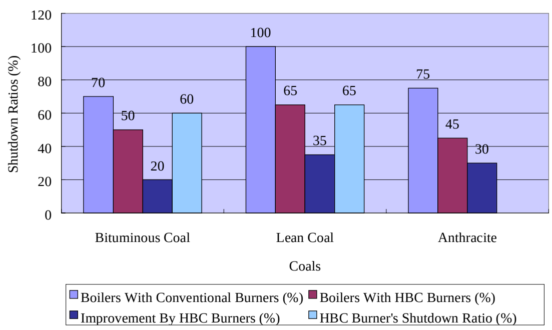


Figure 4 NO emission of HBC burners

Figure 5 Shutdown rations of HBC burners and boilers with them

HBC burners provide a cheap, convenient, and easy way to reduce NOx emission for China. Nozzles of HBC burners have not noticeable difference from those of the conventional burners with regard to their arrangement. The key difference between the two types of burners lies in that HBC burners have louver enrichers, while the conventional burners don't. However, the louver enricher is not large in size. In fact it is very convenient to place the enricher into the fuel transport pipeline just before the burner nozzles, or in the wind box. The only thing to take special consideration is the erosion of the blades, which is quiet easy.

Flame Stability of HBC Burners and Boilers with Them

The fact that the fuel-rich stream has much higher coal concentration than the coal-and-primary-air stream of the conventional burners ensures that HBC burners have very good flame stability. Figure 5 shows the shutdown ratio (namely the minimum load at which the boiler can maintain its flame stability without resorting to supporting fuel oil) of HBC burners and boilers with HBC burners. When low rank coals were fired, HBC burners could improve the shutdown ratio by 30 to 35 %. For tangentially fired boilers of larger capacity fired with anthracite, as illustrated by Figure 6, HBC burners can make boilers operate stably at 45 % MCR without any supporting fuel oil. This was achieved by operating only the bottom burners (half of all burners) at their rated outputs. In fact HBC burners had further potential to improve the shut-down ratio, as the HBC burner generally has the ability of sustaining flame stability at 60 to 65 % of it rated output, Figure 5, although the figure might be a bit higher than that when anthracite is fired.

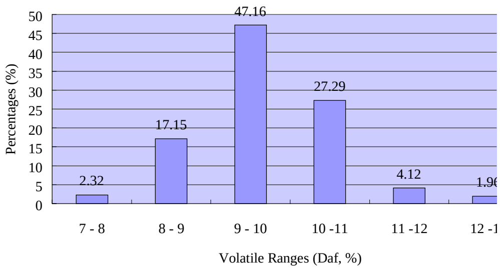


Figure 6 Volatile distribution of coals used for operation below 50% MCR

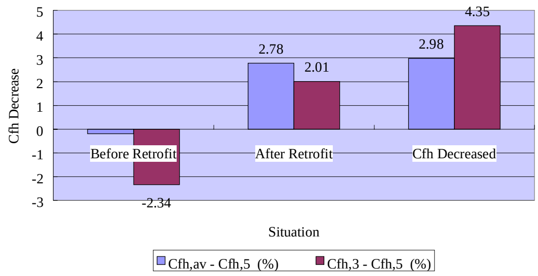


Figure 7 Comparison of unburned combustibles before and after adopting HBC burners

This was a great break through, not only because that is the first time to make a anthracite fired boiler operate stably below 50% MCR without supporting fuel oil, but also because it will provide a bright perspective for tangentially fired boilers in the anthracite fired power plant. The down-firing boiler was said have better flamed stability for anthracite. However, the W-shaped flame boilers met many difficulties before they could provide satisfactory operation with Chinese anthracite, although they cost more and take more land than the tangentially fired boilers. HBC burners will provide a new solution to the problem of utilising these difficult coals.

Slagging

All applications successfully avoid slagging. For example, Boilers fired with bituminous coal are able to operate continuously at rated load without forming serious slagging near the nozzles, which occurred frequently before adopting HBC burner. While anthracite fired boilers do not experience extinction cause by dropping-down slag lumps any more. These have confirmed that HBC burners have very good ability to resist slagging formation or accumulation.

Combustion Efficiency of HBC Burners

The efficiency of lean coal fired boiler without HBC burners were terribly low, because the boiler could not operate stably. The efficiency was greatly increased by the adoption of HBC burners. However, it was not enough to conclude that the HBC burners have the merit of high efficiency. The boilers fired with bituminous coal had very high combustion efficiency, and HBC burners remained it unchanged.

The best demonstration is obtained form the anthracite fired boiler. The combustion efficiency of the boiler had been reasonably high with respect to anthracite. To get a more reliable data, operation data of all the boilers in the same power plant were collected. Three months' burnout data before the adoption of the HBC burners and two months' data after the retrofit were taken. Comparison was made between the mean unburned combustible content of #5 boiler, in which HBC burners were adopted, and the average unburned combustible content of all other boilers. A comparison was also made between #5 and #3 boiler. The latter had been the most efficient one before the retrofit of #5 boilers, Figure 7.

It is seen that HBC burners can decrease the unburned combustibles by 3 ~ 4.3 %, which corresponds to a 1 ~ 1.5 % improvement in boiler's combustion efficiency.

Therefore, we may conclude that HBC burners can improve boiler's burnout, or remain high combustion efficiency.

4 CONCLUSIONS

The combustion technology should also enhance flame stability and slagging resistance, besides reducing NOx emission and maintaining high efficiency, when low rank Chinese coal is fired. The Horizontal Bias Combustion (HBC) burners are capable of meeting all the requirements simultaneously. Applications of HBC burners in boilers of different capacities and with various types of coal proved the merits of HBC burners. The HBC burners are capable of abating NOx emission by up to 54% and ensuring the boiler to operate at 45% of MCR without resorting to supporting fuel oil, with an improvement in shut-down ratio by 20 ~ 35%. They can also increase combustion efficiency, or remain a high value. Slagging is also avoided. It is a technology of multifunction, and therefore, of great promise.

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6 REFERENCES

- Feng Junkai (1995). How should the combustion method in utility boilers be developed from the viewpoint of coal properties in power plants? Collection of Annual Reports (1990 ~ 1994), State Key Laboratory of Efficient and Clean Combustion of China, Tsinghua University, April, 1995, pp. 33-43.
- Gu Pan (1992) Study on pulverised coal particle structure and gas stream entrainment properties and their influence on combustion, Dissertation, Xian Jiaotong University, pp. 1-10.
- Sun, Shaozeng (1995). Study on Horizontal Bias Combustion pulverised coal burners, Dissertation, Harbin Institute of technology, pp. 3.
- Xu, X. C. and Zhang, X. Y. (1991). Recent research work on coal combustion in China, Proceedings of the 2nd International Symposium on Coal Combustion, China Machine Press, pp. 8-12.
- Yuan Ying and Zhao Zhonghu (1988). Current status and prospect of power generation by low rank coal in China, Thermal Power Generation, 1988, No. 6, pp. 1-41.
- Zhang Mingchuan (1990). Pulverised coal ignition and flame stability analysis for tangentially fired utility boilers, Dissertation, Tsinghua University.